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DEGASSING OF CAST STEEL

by

C. W. Briggs

This article is Part II of "The Deoxidation and Degassing of Cast Steel", the second exchange lecture between Steel Founders' Society of America and The British Steel Castings Research Association, which was delivered by the author on October 23, 1958, in Harrogate, England. The first lecture was given by Messrs. T. A. Cosh and L. W. Sanders at the 1957 Technical and Operating Conference of the Steel Founders' Society of America in Cleveland, Ohio.

Gas Content of Cast Steels

Studies have been made [1,2,3] which indicate that the gas content of carbon and low-alloy cast steels, as produced in production furnaces for steel castings is, for the most part, fairly low (See Table I).

The normal expected hydrogen content at meltdown for carbon and low-alloy cast steel is in the range of 2.5 to 3.3 ppm and at the end of the oxidation period, prior to deoxidation, the hydrogen content of properly made cast steel is, in most cases, below 2.5 ppm. However, the hydrogen content of the steel in the ladle usually will be higher, and a value of 3.0 ppm normally can be expected.

Hydrogen contents of high-alloy cast steel in the ladle usually will be in the range of 4.0 to 11.5 ppm.

The reason that carbon and low-alloy cast steels normally are produced to the low hydrogen contents listed above, is that it is a general foundry practice to employ a long vigorous boil, by the use of iron ore or oxygen after the steel has completely melted.

Effect of Hydrogen and Nitrogen on Cast Steels

It has been definitely established[4] that hydrogen is the principal cause of abnormal loss of ductility of the type which can be eliminated by aging. While stresses and the metal structure play a part in the ductility loss, the effect of hydrogen is much larger than the sum of other effects.

Nitrogen cannot be connected with this type of ductility loss, since (1) its amount is not correlated with ductility values, and (2) nitrogen content is not changed by aging the steel. This, however, does not exclude nitrogen as a cause of low ductility in cast steel. It has been shown that aluminum nitrides can result in a decrease in ductility and concomitant rock candy fracture. Therefore, it is to the steel foundryman's advantage to produce steels of low nitrogen content.

The amount of hydrogen which must be present to give a specified loss of ductility depends on the structure, cleanliness and history of the steel. A steel (solid state) of hydrogen content below 0.45 ppm permits a ductility practically as good as that which would be obtained with a hydrogen-free steel. Cast steel, at normal temperatures, and containing about 1 ppm hydrogen, may have a ductility of only 80 to 85 percent of the hydrogen-free value, or it may be as high as 90 percent of this value, depending upon the steel and the treatment. Steels with hydrogen contents in the range of 3 to 4 ppm can be expected to show no more than 15 to 30 percent of the original ductility value.

The loss of ductility increases very rapidly with increases in the section size of the casting and with the distance below the surface. This condition arises from the fact that there is a large surface loss of hydrogen during slow cooling as well as a large segregation of hydrogen which takes place ahead

TABLE I

GAS CONTENT OF PRODUCTION CAST CARBON AND LOW-ALLOY STEELS

Process	Heat Size Tons	Hydrogen ppm: Meltdown Range	Hydrogen ppm: Prior to Deoxidation Range	Hydrogen ppm: Ladle Range	Hydrogen ppm: Avg.
Acid Electric	1-8	1.1 - 3.2	0.9 - 2.2	1.3 - 3.4	2.4
Acid Open-Hearth	10-100	1.9 - 4.5	1.9 - 3.2	2.4 - 3.6	3.0
Basic Electric	3-10	2.1 - 4.1	1.7 - 4.0	2.6 - 5.0	3.4
Basic Open-Hearth	40-70	1.8 - 2.5	2.0 - 3.4	2.3 - 3.7	3.1
		Nitrogen wt. %			
Acid Electric	1-8	0.0077-0.0100	0.0031-0.0055	0.0053-0.0120	0.0076
Acid Open-Hearth	10-100	0.0040-0.0052	0.0035-0.0048	0.0053-0.0067	0.0057
Basic Electric	3-10	0.0056-0.0127	0.0047-0.0076	0.0050-0.0070	0.0063
Basic Open-Hearth	40-70	0.0037-0.0047	0.0026-0.0035	0.0031-0.0055	0.0048

of the line of freezing in heavy sections. The residual hydrogen content of 1-inch sections is usually only 1/6 to 1/3 of the content of the liquid steel from which it was cast and is usually of such a small content that it has little effect on the ductility. The hydrogen content at the center of a 4-inch section cast against metal chills may rise to twice the hydrogen content of the molten steel, with almost complete loss of ductility. The same size section, sand cast, had a hydrogen concentration at its center which was 85 percent of the content of the molten steel.

The hydrogen content at the center of a 6-inch sand cast section was approximately equal to the content of the liquid steel from which it was cast. Each of these cases represents a concentration sufficient to result in very extensive losses of ductility. It should be pointed out that inclusion types have no effect whatever on the abnormal loss of ductility resulting from the presence of hydrogen. The lowering of ductility as a result of inclusions, and the loss of ductility because of hydrogen, appear to operate very nearly independently and are additive only to a limited extent. Hydrogen and nitrogen also can be responsible for promoting porosity in castings.

Steelmaking for Gas Control

The rapidity or violence of the boil, rather than the total boiling time, apparently is the only important factor operating to reduce the hydrogen content during steelmaking. The hydrogen content of the steel can be reduced to about half the value which otherwise would be retained if a good boiling technique is used. Major considerations, other than a vigorous boil, which should be adopted are: (1) limitation of time when the heat is inactive or blocked, and (2) improvement in furnace and ladle handling to insure that the refractory material is as free of moisture as possible.

Final hydrogen in the liquid steel seems to be the net result of six separate fractions:

H_2 from metal charge	+	H_2 absorbed or lost in melting	−	H_2 eliminated by the boil				
+	H_2 absorbed in furnace in finishing	+	H_2 absorbed in tapping into ladle	+	H_2 absorbed in the mold			
=	Final total H_2							

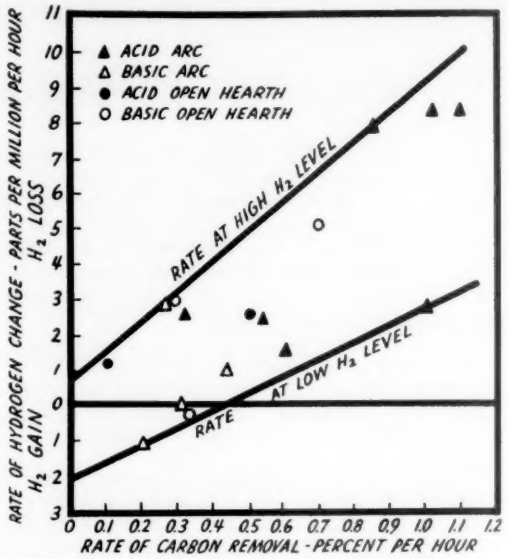

Figure 1—Effect of rate of boil on hydrogen content of commercial cast steels.

These phases are not equally important in all practices and all types of cast steels. In some cases, hydrogen at meltdown is very high from I and II, especially in high-alloy cast steels, while carbon and low-alloy cast steels seldom contain more than 4 ppm hydrogen at meltdown.

The hydrogen that can be eliminated by boiling is best illustrated by Figure 1 which shows the comparative rates of carbon and hydrogen removal at time of maximum bath activity for a series of commercial casting heats. The rate of hydrogen removal on the amount of hydrogen present and on the competing reabsorption of hydrogen from the furnace atmosphere, precludes the possibility of any legitimate single line representing the average rate of hydrogen removal. This plot indicates that no one type of furnace gives high or low rates of hydrogen removal. The most important difference between furnaces shown in this figure is that the boil intensity in the acid arc is usually much greater than in the other types.

The plot indicates that hydrogen is slowly lost if the meltdown hydrogen content is high and there is only a mild boil. The rate of hydrogen elimination can be seen to increase regularly as the boil becomes more violent. On the other hand, if the meltdown hydrogen content is low, i.e., 2 ppm or less, hydrogen actually may be picked up at any time except when the boil is sufficiently violent to eliminate carbon at a rate of more than 40 points per hour.

The reduction of the final furnace hydrogen below 2 ppm is the objective of improved steel-

making practice. The attainment of this objective requires continued hydrogen reduction at the lower edge of the band of Figure 1; hence, steel foundry melters in the United States are admonished to carry on carbon removal at the rate of about one point per minute or greater.

Time in the inactive or blocked condition must be minimized. High furnace atmosphere humidity from new linings, patches, wet materials and highly humid days can effectively increase the hydrogen content of the steel during or after the boil if a very vigorous boil is not maintained in the bath. A late boil can be just as effective as one at meltdown and can be easily attained today through the use of oxygen injection.

A most obvious and promising point for plant attack on the hydrogen problem lies in the reduction of the moisture content of ladles. An investigation of 19 commercial heats was made on this point. Six of these heats finished in the furnace with a hydrogen content of 2 ppm or less. The good melting record of 5 of these was spoiled by a hydrogen pickup of 1 to 2 ppm of hydrogen in the ladle. Five additional heats (10 out of 19) also had noticeable hydrogen increase from the ladle raising the final hydrogen in the extreme case to the very undesirable level of 5 ppm.

Moisture present from new refractories, patches, cooling ladles with water, etc., is the cause of the hydrogen increase. All newly lined ladles, no matter how long they are heated, will result in hydrogen pickup by the metal in the ladle.

The total nitrogen content of most cast steels is in the range of 0.005 to 0.01 weight percent, and during the oxidizing period the nitrogen removal from the bath closely parallels the drop in carbon content. An increase in nitrogen content usually occurs with alloy additions, and on tapping.

Vacuum Stream Degassing

The steel casting industry in the United States was very much interested in the Bochumer Verein development of stream degassing of steel castings. It is reported[5] that for a 0.35 percent carbon steel, gas reductions are as follows:

	Normal Steel	Stream degassed steel
Oxygen	0.007%	0.002%
Nitrogen	0.006%	0.004%
Hydrogen	5.9 ppm 5.7 ppm	3.1 ppm 2.3 ppm
H_2 Concentration in a 20.8 inch ingot		
Center	3.0 ppm	0.8 ppm
Edge	1.0 ppm	0.8 ppm

No steel foundry in the United States, as of July 1958, is producing steel castings by the vacuum stream degassing method. However, stream degassing studies are going on at the Applied Research and Development Foundry of one company that produces steel castings. Another steel foundry company is building a sizeable degassing chamber for primary use in degassing steel for rolling mill rolls.

The steel casting industry in the United States has not considered vacuum stream degassing because it can produce steel of 2 to 3 ppm in the ladle, and up to the present time, there has been no call for thick walled castings of low hydrogen concentration within the heavy sections.

Gas Flushing

A few studies have been made, by steel foundries in the USA, of gas flushing steel in the ladle or in induction melting furnaces. The flushing media studied commercially have been:

1—Argon
2—Dry Air
3—Polytetrafluoroethylene

The experiences with gas flushing have been varied. In most cases the flushing has been limited to the stainless steels, and only small consideration has been given to the low-alloy steels.

Argon flushing of carbon and stainless cast steels has not shown any advantage. In one cast a low-alloy cast steel melted in an induction furnace was blanketed with argon gas during melting and flushed with argon gas after melting. Hydrogen analysis showed no improvement over normal heats. Reports from steel foundries using argon gas for flushing stainless steel, vary from no advantage to a reduction in one case of 8 ppm to 4.9 ppm of hydrogen. The quantity of argon employed also has been quite variable, ranging from 6 to 90 cubic feet per ton of steel with 10 cubic feet per ton as the most accepted quantity.

Experimental studies[6] in flushing high-alloy and SAE 4330 steels with argon showed that the quantity of hydrogen removed per unit volume of flushing gas, is proportional to the hydrogen content. Also the efficiency of argon flushing in terms of the amount of hydrogen removed per unit volume of flushing gas, is roughly comparable to that of CO gas produced during a carbon boil.

Perhaps one of the reasons for the indifferent success is the method of introducing the gas into the furnace or ladle. A single tube produces large and violent eruptions which are not too efficient.

Open-end tubes, replaced by ceramic tubes, produce small bubbles and improve the efficiency of hydrogen removal. One foundry reported that at best they could obtain only a drop of 0.5 ppm hydrogen by using an open-end pipe.

Dry air has possibilities as a method of flushing steel. This method is not used in a steel foundry, as far as the author knows, but it is used by wrought stainless steel producers in 10 to 30-ton electric furnaces. Regular plant compressor air is dried in equipment (BWC Pittsburgh Lectrodryer) with pressure regulated to maintain 25 to 30 psi at the furnace. Dew point is usually kept below minus 40 degrees F. The lance consists of a ½ or ¾-inch pipe. Air is used at a rate of 250 or 300 cfm.

Flushing will be carried on for 2 to 6 minutes just prior to tapping, depending on the size of the heat (approximately 12 seconds per ton). In some cases a subsequent ladle flushing of short duration, such as 30 seconds, is employed.

Information on the drop in hydrogen content by the flushing practice is meager, but the companies employing the dry air practice advise that the incidence of hydrogen-wild heats and gassy tests, even during periods of high humidity, is extremely rare.

One of the newer materials used for flushing molten steel is a plastic (polytetrafluoroethylene) consisting of approximately 25 percent carbon and 75 percent fluorine and known in England as fluon, and in the United States as Solo-H. It is stable up to 600 degrees F at which temperature it begins to release fluorine. The reaction is slow enough at steelmaking temperatures to give a reaction of 40 to 80 seconds. It is stated that the efficiency of this material as a degasifier increases with the increase in bath depth; therefore, it is best used in the ladle.

A few steel foundries have used this plastic material but specific analytical data are meager. It is supposed to remove half the hydrogen in stainless steel if the hydrogen level is around 8 to 10 ppm. The material is used in quantities of about 2 ounces per ton of steel. Two minutes are considered the minimum allowable reaction time.

Effect of Hydrogen on the Properties of Cast Steel

Previous investigations[4] have established that hydrogen can cause a temporary, abnormal loss of ductility in steels. Attempts to show this relation quantitatively have been complicated by inaccuracies in measurement, and by the highly segregated character of the hydrogen in the steel, resulting in differences between the samples tested physically and the adjacent portions which are analyzed for hydrogen.

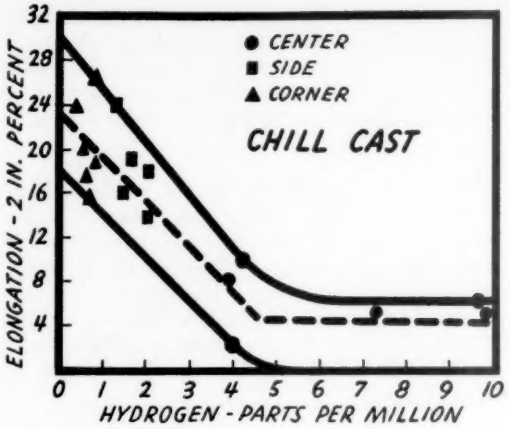

Figure 2—Relation between elongation and hydrogen content for chill cast 4 x 4 x 12-inch castings for 6 heats of carbon steel. Composition: carbon 0.26, manganese 0.60, silicon 0.50 percent. Ladle hydrogen content 3.1 to 5.5 ppm.

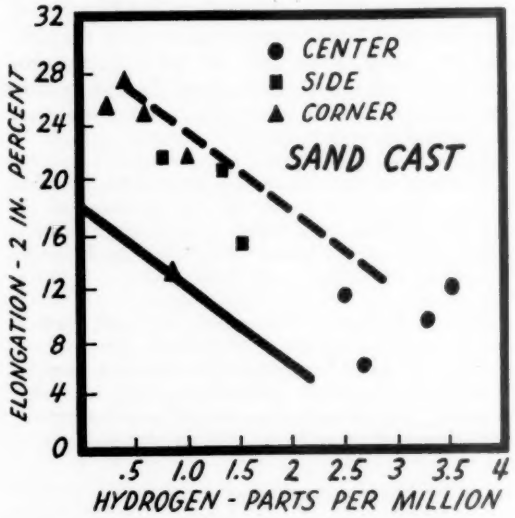

Figure 3—Relation between elongation and hydrogen content for sand cast 6 x 6 x 12-inch castings for 4 heats of carbon steel. Ladle hydrogen content 3.1 to 4.1 ppm.

The loss in ductility is considered temporary because ductility can be restored by aging. However, flakes or shatter cracks can form with permanent damage to the section and to the casting.

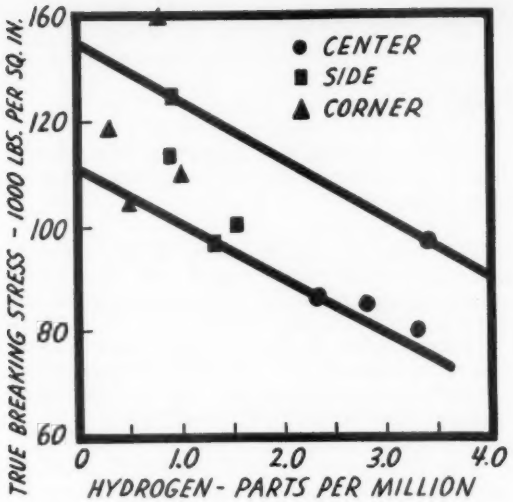

Figure 4—Relation of true breaking stress and hydrogen content for sand cast 6 x 6 x 12-inch castings for 4 heats of carbon steel. Ladle hydrogen content 3.1 to 4.1 ppm. Breaking stress = max. load/final reduced area.

An indication of the effect of the hydrogen content on the elongation of carbon cast steel is shown in Figure 2. These studies were made on a 4 x 4 x 12-inch bar cast into a chill mold (ingot mold) to solidify the casting rapidly. It will be observed that the surface layers of the bar show hydrogen contents of less than one part per million while the center of the bar shows hydrogen concentrations of upward of 10 ppm. The ductility drops off very rapidly up to 4.65 ppm of hydrogen.

Comparison can be made with what happens in a sand casting by referring to Figure 3. In this case a 6 x 6 x 12-inch bar casting is made in a sand mold. A similar drop-off in ductility is obtained; however, the casting is larger, being 6 x 6 x 12 inches, and the hydrogen segregation at the center of the section is not as great as in the case of the faster solidifying bar cast in a chill mold. Incidentally, the hydrogen content of the steels in the ladle was not too great, being only 3 to 4 ppm.

The effect of hydrogen on the reduction of area is similar to that on elongation. Tensile strength values indicated a continuous downward trend extending to a 45 percent loss of 80,000 psi at 10 ppm hydrogen for the conditions of Figure 2. However, this trend includes the effect of different cooling rates at the different sample positions.

It is known that the true breaking stress, that is, maximum load divided by final reduced area, is nearly independent of ordinary variations in composition and heat treatment for a given class of steel. A plate of this quantity against hydrogen content for 4 heats of sand cast steel of Figure 3 is given in Figure 4. In this case, variations in the cooling rate of the samples have been eliminated.

Thin sectioned steel castings do not normally show much loss in ductility. However, it has been observed, many times, that a minimum ductility requirement of a customer's specification cannot be passed without the aging of the test bars produced from 1-inch thick coupons; but aging at room temperature or at a low temperature soon restores the ductility values to those normally expected.

Manufacturers of heavy equipment are more concerned about the effect of hydrogen on the properties of the castings. For example, a manufacturer of turbines for nuclear and electric power plants states, concerning castings, that they can say with little reservation that they have found that the ductilities of heavy sections are markedly improved by obtaining hydrogen contents of the steel in the ladle below 3 ppm. It has been their experience, also, that this level is necessary in order to avoid cracking of alloy castings whose design is such as to produce high residual stresses. They also add that they are not certain they are satisfied with the levels of 2 to 3 ppm hydrogen, especially in steels going into turbine application.

It is felt that much more attention will be given to this subject by steel foundrymen in the near future, and it is believed that hydrogen analysis equipment will become a required tool, and routine hydrogen analysis a production procedure.

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TOLERANCES FOR STEEL CASTINGS*

by

Paul H. Stuff**

All castings are subject to variations in dimensions and conditions of surfaces; both of these have an effect on the tolerances to be expected. The controlling elements are design and method of manufacture. Steel presents many more exacting problems in casting than other metals. This results in the necessity for close cooperation of the design engineer and the producer. It is important that each is fully aware of the problem if casting tolerances are of importance.

From a review of existing data it is doubtful if the designer or producing foundry is fully aware of their limitations or possibilities.

The introduction of die, permanent mold, and investment casting methods has awakened the designer to tolerances which were hitherto impossible and not attainable by conventional foundry practice through the common use of sand molds. Such methods are restricted in their scope with respect to design, size, dimensions, casting weight, thickness, etc., which limit them to the small casting field. This means that the bulk tonnage of castings is outside their range of manufacture and must be produced by methods which have been in use for centuries.

No doubt, the tolerances and surface finish made possible by such methods have influenced the thinking of the design engineer and resulted in endeavors to place a comparable demand on other types of production. This is as it should be. Some foundries are now realizing that they can produce steel castings to tolerances and surface finishes by conventional procedures which previously were thought impractical. This influence has been the same on other cast metals.

Regardless of the techniques employed in producing a casting, there are many factors which influence the dimensional accuracy and surface finish. The term casting includes an infinite variety of sizes, shapes and geometric proportions, and some of the factors which affect the accuracy and finish are:

Design	Shape	Gates
Weight	Contour	Risers
Length	Molding	Cleaning
Width	Cores	Heat Treatment
Thickness	Metal	Grinding
Height	Chemistry	Warpage
Pattern	Pouring Temperature	Camber
Shrinkage	Cooling Conditions	Coining

Several of these could be subdivided further, thereby increasing the number of variables influencing casting dimensions.

Thus, a casting may be subject to different combinations of many variables and will respond in a manner peculiar to itself. Although established data for a given casting may be applied with reasonable accuracy to other castings of similar size and shape, extension of this data to castings of unrelated design can only indicate approximate results. The casting technique does not alter these conditions.

Since die or permanent mold methods of producing steel castings are not in common use and investment casting practice is not to be considered as a part of this presentation, the majority of the data to follow will concern practices other than these three, although comparative reference will be used occasionally. The methods commonly in use besides these for steel are:

Sand Casting
CO_2 Process
Shell Casting (C Process)
Shell Casting (D Process)
Special Process (Ceramic Other than Investment)

When reference is made to sand casting, one normally thinks in terms of producing castings in sand as practiced by foundries since the beginning of the casting art. However, casting is an art which is rapidly becoming a science. The other methods also employ sands or similar refractory materials appropriately bonded to form the mold or cores. All the aspects of each, or the numerous factors involved, cannot be covered in this brief paper, but certain data should be of interest and serve to indicate the present status with respect to tolerances and finish.

Factors influencing a casting were listed earlier. Let us review a few of them with respect to their general influence on the casting methods. Design, weight, length, width, thickness, height, shape and contour should determine the casting methods which can be used. Very thin castings will demand investment, special ceramic or shell in preference to sand or CO_2 in order of their listing with respect to increasing metal section. On the other hand, the upper limitations of the weight, length, width and height throw a definite restriction on the investment or shell process. The special ceramic process, other than investment, offers a happy medium but with restriction. Tolerances and surface finish obtainable with various processes are in decreasing order as follows:

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* Presented at the Conference on Steel Castings, April 16, 1958, sponsored by the Corps of Engineers, Fort Belvoir, Virginia.

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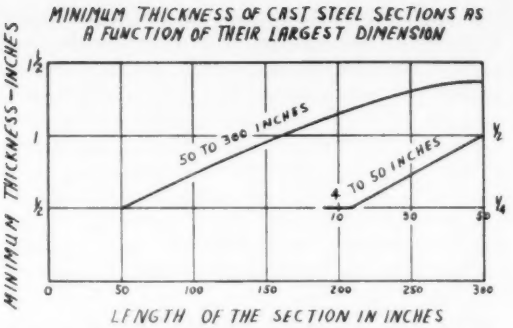

Figure 1—Minimum thickness of sections as a function of their largest dimension. Note: The curve represents the best of design conditions wherein molten steel enters at one position on the casting and must run the lengths prescribed on the chart. Special techniques will permit the running of thinner sections than shown.

Investment Casting
Special Ceramic (Other than Investment)
Shell Casting (C & D Process)
CO_2 Process
Sand Casting

With the major tonnage of steel castings being made in sand molds, tolerances and finishes expected of them should be the first order of consideration.

The minimum thickness is normally considered to be ¼ inch for sand castings. The fluidity of steel in comparison with other metals is of a low value. In order that sections can be completely run, it is necessary to adopt a minimum section thickness. Steel does not behave in a mold like other metals. It has a tendency to roll rather than run. This self-possessed trait puts it in a family by itself and creates a problem in surface finish not experienced with other metals.

Metal cools as it runs in a mold section, thus a thin section near a gate which is delivering hot metal will run, whereas the same section some distance from the gate will not cast. Since the positioning of the gate is not designed into the casting, the ¼-inch minimum metal section is recommended.

Steel flows best for a given thickness in a narrow, rather than a wide, area. If the ¼-inch sections become longer than 12 inches, the minimum section should be increased. The chart shown in Figure 1 provides curves, representing preferred design conditions, wherein molten steel enters the mold at a prescribed position and must run or roll the length shown for a given section thickness. By application of special techniques, the foundry can pour longer sections through thinner sections but this entails added cost.

For investment casting, the ¼-inch metal section could just as easily be the maximum rather than the minimum. This is strictly due to process characteristics but does clearly demonstrate how one factor enters into the matter of obtainable tolerances. The section ranges for the other mentioned processes fall between sand and investment methods.

Steel shrinks in volume as it cools from time of solidification to room temperature. This shrinkage is higher for steel than most other metals. The amount of this solid contraction will vary for the type of steel. In the construction of patterns, compensation is made for this contraction and is known as patternmaker's shrinkage. When steels are allowed to contract in casting, the normal shrinkage allowance without hindering this contraction is approximately 9/32 inch per foot for low carbon or medium alloy steel and 5/16 inch per foot for stainless steels. Some relative values for various cast metals in the unrestricted state are shown below:

Metals	Contraction Inches per Foot
Steel—Low Carbon	9/32 - 3/16
Steel—Stainless	5/16
Gray Iron (Nodular)	1/8
Aluminum	5/32
Magnesium	11/64
Brass	3/16
Bronze	1/8 - 1/4

Due to casting design, mold and cooling conditions, etc., this normal contraction may not proceed according to expectations. In many cases there are conditions existing which necessitate the use of several pattern shrinkage allowances in the same mold. Shrinkage used may range from 0 to 9/32 inch per foot for a plain carbon steel. Molding methods in various foundries are often so varied that castings made by each from the same pattern would not be alike. Tolerances in one shop would be well within anticipation while those in another would be entirely out of range. This dictates a policy of having the foundry produce the pattern as well as the castings where tolerances are of any concern, or at least having the foundry control the pattern construction.

To illustrate how design can affect this contraction, three rather simple examples are shown in Figure 2. It is assumed that each of these is poured in 0.35 percent carbon steel in a regular sand mold.

Bar A is round and has no apparent restrictions. It will take full contraction upon cooling since it is not hindered and full patternmaker's shrinkage will result. Since measurements show a contraction of 2.40 percent, the equivalent of 0.288 inch per foot, a patternmaker's shrinkage of 9/32 inch per foot would give a bar to the desired length.

Bar B is also round but restricted by knobs on each end. The contraction on this bar is found to be 1.64 percent. This is the equivalent of 0.196 inch per foot or slightly over 3/16 inch per foot. In order to secure normal tolerances, a patternmaker's shrinkage of 3/16 inch per foot would be required.

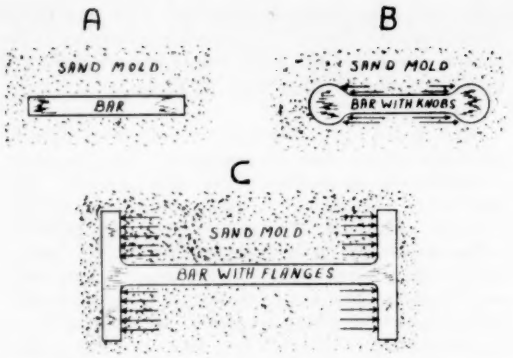

Figure 2—Patternmaker's shrinkage and hindered contraction: (A) straight bar, (B) bar with knobs, (C) bar with flanges.

Strangely enough, this commonly used figure in steel pattern construction has resulted in many controversies between purchaser and producer when patterns are not produced by the foundry.

Study of bar C will help further clarify this point. It is not only round like the other two, but it is further restricted by flanges on each end. This design allowed contraction of 0.92 percent of the pattern length. Nothing was changed throughout these tests except design. Mold materials and methods have remained constant.

The patternmaker's shrinkage is now 0.110 inch per foot or about 7/64 inch per foot. This is considerably different than the 9/32 inch per foot for the A bar. Even this is not the minimum, as values of 0.50 percent, or approximately 1/16 inch per foot, patternmaker's shrinkage are encountered under what are considered normal conditions. Under adverse conditions the value has been known to be negative.

Other factors entering into pattern construction are distortion, camber, warpage, heat treat, sand expansion, gating, risering, pouring, temperature, metal, etc. The ability of the pattern to meet all of these numerous requirements determines the tolerances and finish to be acquired. This should clearly illustrate the necessity for consultation between the buyer or engineer and the supplying foundry when dimensional tolerances or other items are important.

A casting can be only as accurate as the pattern and the maintenance of this accuracy through its useful life. This accuracy involves all the factors just mentioned plus the added necessity of very careful prior study of similar casting design to produce an acceptable pattern without the repeated use of trial and error methods to attain dimensions desired where tolerances are very rigid. One can readily see that this could involve many things, and there is no need to attempt to name them as a little thought will be all that is necessary to bring them to one's attention.

In addition to the accuracy of the pattern, the materials of construction such as soft wood, hard wood, plastic, or metal, methods of mounting for production—for example, loose, sweep, skeleton, solid or split, cope and drag, match plate, etc.—have a profound effect on the final product. This applies to core boxes, jigs, and other mold producing accessories including maintenance of accuracy of mechanical handling equipment where employed. Proper pattern equipment handled in the correct manner can produce surprisingly accurate sand castings.

Even with the utmost planning and precautions, often the only economical solution to meeting certain tolerances and finish requirements is machining certain surfaces to attain the desired objective. This applies to all methods of molding and is not restricted to conventional sand methods.

When machining is required, sufficient excess metal should be allowed to satisfactorily accomplish the necessary operations. This allowance, commonly called finish, will depend upon all the previously mentioned factors affecting casting accuracy and finish plus methods of machining, setup, jigging or locating points, surfaces to be machined, surface finish expected, etc. These allowances may require as much as ¾ inch for large sand castings. One very good rule is the allowance of sufficient metal to be sure the first cut remains, if possible, in its entirety below the surface of the metal by at least 1/32 inch.

Since the accuracy of the casting, its surface finish and necessary machining allowance all depend on common factors, it may be well to consider what may be expected of each for conventional sand castings. By now it should be fully realized that each casting is a problem within itself regardless of method or process of production. Tolerances and surface finish are uppermost in this respect.

Some relevant tolerance data for unmachined sand castings are shown in Table I.

TABLE I
DIMENSIONAL TOLERANCES FOR STEEL CASTINGS WHICH ARE NOT TO BE MACHINED

Tolerance	Smaller than 12 inches	Between 12 and 36 inches	Between 36 and 120 inches
Average	0.06+0.006D 1/16" min.	0.06+0.006D	0.08+0.006D
Concise	0.04+0.005D 1/16" min.	0.05+0.005D	0.07+0.005D
Minimum	0.03+0.004D 1/16" min.	0.04+0.004D	0.06+0.004D

D=longest dimension of the casting in inches.

These average values are those suggested to be employed and in no case should a value below the minimum be used. The concise values are those to be used by a foundry which has had experience in the particular design and knows whether or not they can be maintained.

TABLE II
A GUIDE TO MACHINE FINISH TOLERANCES

Casting Diameter Inches	Machine Allowance on the Outside Radius Inches Rings Spoked Wheels Spoked Gears Circular Shaped Castings
Up to 18	1/4
18 to 36	5/16
36 to 48	3/8
48 to 72	1/2
72 to 108	5/8
108 and up	3/4

Bore Diameter Inches	Bores Machine Allowance on Bore Radius Inches
Up to 1	Cast Solid
2 to 7	1/4
7 to 12	3/8
12 to 20	1/2

For machining allowances a fair consideration would be that shown in Table II.

It is to be pointed out that certain positions on a casting in respect to the mold will require more machining allowance than others. For example, the cope side of a large casting may require $\frac{5}{8}$-inch allowance, whereas on the drag or side walls $\frac{3}{8}$ inch may be ample.

The surface finish of the machined surfaces for steel castings is equal to that expected from forgings or other comparable wrought products of equivalent chemistry and heat treatment. Therefore, the standard surface finish specifications advocated by the American Standards Association are applicable to machined steel castings. The surface roughness is commonly expressed in terms of rms, meaning root means square average heights in millionths of an inch for relatively finely spaced surface irregularities. This is easily established for machined surfaces, but it is rather difficult to apply these values to castings, since there is no common roughness width or spacing existing on casting surfaces comparable to machined surfaces. Nevertheless, we are continually attempting to classify cast surface finishes in rms values with no practical means of evaluation. The instruments available for machined surfaces can be used, but what actually is being determined is a waviness relation rather than a roughness value.

Instruments commonly used for machined surfaces are of the Tracer Profilimeter or Brush Surface Analyzer types. The Profilimeter will measure roughness widths up to 1/32 inch, whereas the

TABLE III
GENERAL COMPARISON OF CASTING METHODS

Casting Requirements	Sand Castings	CO_2 Castings	Shell Castings	Ceramic Castings	Investment Castings
Micro-In Surface Smoothness	200-500	150-400	100-220	80-150	40-125
Thinness of Metal Section (Inches)	Fair 3/16	Fair 3/16	Good 5/32	Very Good 3/32	Excellent 1/16
Base Tolerances Inches per Inch	±0.030	±0.020	±0.008	±0.006	±0.005
Added Tolerance Across Parting or Shift	±0.020	±0.020	±0.010	±0.010	No Parting
Intricacy	Fair	Good	Very Good	Extra Good	Excellent
Metal Limitations	None	None	Some Low Carbon Steel	None	None
Finish Allowances	Most	Most	Average	Least	Least
Size Adaptability	No Limit	Slight Limit	Small Castings Up to 100 lb.	Small Castings Up to 100 lb.	Small Castings Up to 40 lb.
Pattern Costs	Low	Low	High	Average	High
Lead Time	Shortest	Shortest	Long	Short	Longest
Prototype Rating	Not Applicable	Not Applicable	Generally Not Applicable	Low Cost	High Cost

NOTE: This is a comparative table only and gives relative information for average lightweight castings in general. For accurate information, it is suggested that contemplated design be submitted to the foundry engineer for comments.

Brush units are normally good for widths of smaller magnitude. Until better methods for cast surfaces, such as photographic transfer, are developed, these instruments will remain a makeshift solution. Many methods of comparing surface finishes have been advocated by the use of standard samples, but no acceptable solution has been evolved. Using rms values, sand cast finishes can range from 200 to 1000. The controlling factors are, largely, what is wanted and how much one will pay.

Perhaps a tabulated comparison of expected values for various methods of production may be the simple way for evaluation. With this in mind, Table III is presented based on castings of comparable weight and dimensional range.

Only a few of the factors which were listed in the first of this presentation have been given any detailed consideration in their effects on tolerances or surface finish of steel castings. Unfortunately, the scope does not permit such coverage. In conclusion, it is gratifying that the foundry industry is making rapid progress in producing castings to closer and more exacting tolerances with improved surface finish. By continued cooperation of the purchaser, designer, and the foundry engineer, this progress shall not cease.

A NEW RESEARCH PROJECT ON DETERMINATION OF THE DISTANCE A RISER WILL FEED 4- AND 8-INCH THICK CASTINGS

Research Project No. 47

Research Project No. 47 was formulated and approved early in the fall of 1958, and the research is proceeding on schedule. Steel Founders' Society's Research Reports No. 13 and No. 30 present information on riser efficiency and the distance a riser will feed various uniform section castings whose thickness does not exceed about 4 inches. These data and the curves obtained from them have been extended to thicker sections because of the practical need for calculating riser dimensions and riser placement on thick-walled castings.

The Technical Research Committee was of the opinion that the industry should have definite information on the distances risers will feed heavier sections rather than to use extrapolated values.

The desired information is to be obtained by studying bars, plates and semi-plates in section thicknesses of 4 and 8 inches at various lengths.

The studies are being carried on at three member foundries. These companies have facilities for radiographing the section sizes under study. All feeding distances are being evaluated by radiographic inspection.

The riser sizes employed on the various castings were calculated according to the methods proposed and in use by Steel Founders' Society. The first study undertaken was to see if the calculated risers were adequate for the casting and did not produce under-riser shrinkage.

The feeding distance in bars is to be determined both when the bars are molded horizontally and vertically. An open-top riser is to be employed only on one end. A third experiment will be to determine the distance an open-top riser will feed bars without the benefit of an end effect. This means that there will be a riser at each end of the bar. About 3 tons of bar castings will be made.

Plate sections are being studied: (1) with a single open, top riser at one end of a plate horizontally molded, (2) an open, side riser along the side of the plate with the plate poured horizontally, (3) open risers on each end of the plate so there will be no end effect, and (4) the plate is cast on edge with a riser at the center of the edge of the plate. These studies will require about 25 tons of steel.

The semi-plates are dimensions between a bar and a true plate. Bars are considered as width being equal to thickness. Shapes are considered plates if the width is greater than 3 times the thickness. Semi-plates are, therefore, shapes greater than $W = T$, and less than $W = 3T$. The studies for the semi-plates are similar to those carried on for the plate castings. About 10 tons of castings are to be made in this series.

The Technical Research Committee plans on reviewing the results of these studies, projecting the data to 12-inch sections and then making one 12-inch casting as a bar and as a plate to see if the extrapolated feeding distance proves out in actual casting conditions. The Committee might, at this time, also decide on additional studies employing exothermic sleeves and pressure feeding to see the effect of these variables on the distance that risers feed.

It is the hope of the Committee that the results of these studies will be available early next fall.

PROGRESS REPORT ON INORGANIC BONDING OF MOLDING MATERIALS

Research Project No. 43

The objective of this research was to study the properties and behaviors of inorganic bonds and to develop materials and processes suitable for the bonding of molding materials for the production of steel castings. Inorganic bonding materials, such as soluble silicates, inorganic gels, hydraulic cements, borates and phosphates, are possible binders for the production of steel castings.

The research on soluble silicate has been published in Research Report No. 42, "Sodium Silicate-Carbon Dioxide Inorganic Bonds for Molds and Cores".

Recent Studies

Major efforts have been directed toward a research for new and potentially useful inorganic bonds. Those investigated are as follows:

1. Inorganic gels
2. Concentrated disperse-phase systems
3. Hydraulic cements
4. Borates
5. Lime bonds
6. Magnesia
7. Calcium silicates
8. Ferric phosphates

The hydraulic cements did not furnish encouraging results. The borates, lime and magnesia were tried, but the results were not promising. These materials were also tried in mixture with no better results.

It did appear that excellent bonds might be prepared from colloidal dispersions of refractory oxides or silicates. Further studies were not conducted because too long a time would be required to develop these bonds, and the cost of the colloids is quite high.

Metaluminate ($NaAlO_2$), sodium hexametaphosphate ($Na_6P_6O_{18}$), phosphoric acid, aluminum phosphate ($Al_2O_3.P_2O_5$) and ferric phosphate all seemed to offer promise as bonds for producing either cores or molds. Each of these inorganic binders was selected for investigation because it possesses all or most of the following properties: (1) the melting points are in excess of 3000 degrees F, (2) they have sufficient viscosity, refractoriness and wetting ability to be considered for bonding sands and (3) each can be converted to a hard, cementitious, stable bond by chemical reaction or by heat.

Sodium Metaluminate

Early work showed that a water solution of sodium metaluminate when added to sand alone would not produce satisfactory molds or cores because the shelf life of heat-cured samples is poor. Sodium silicate was used to replace the water as solvent for the binder. Various ratios were tried to obtain sufficient refractoriness to give the desired collapsibility.

Compositions of greater than 25 percent sodium metaluminate in sodium silicate were not possible because of its insolubility in sodium silicate. Since experiments had shown that when a sodium silicate solution of less than 25 percent of $NaAlO_2$ was used as a binder, the resulting heat or carbon dioxide cured cores did not possess desirable shake-out properties, further studies on this binder were dropped in favor of more promising inorganic binders.

Sodium Hexametaphosphate

Binders composed of sodium hexametaphosphate and water when added to silica sand developed good molding properties, and laboratory samples could be cured at 275 degrees F. Compressive strength at room temperature after baking indicated the binder required additions of refractory materials as an aid to collapsibility (good shake-out properties).

Additions of kaolin did not improve collapsibility, but additions of zirconium oxide (ZrO_2) did.

Binders containing various ratios of kaolin to ZrO_2 were tried. Laboratory tests indicated that when 4 percent of a binder composed of $Na_6P_6O_{18}$, ZrO_2 and kaolin were mixed with silica sand, the results were encouraging in that all of the desirable properties of a bonded sand were found to be inherent in this mix. It had excellent molding properties, good shelf life, apparently excellent collapsibility and sufficient hot strength to prevent hot deformation.

$Al_2O_3.P_2O_5.H_2O$

Sample cylinders formed from 95 percent silica sand and 5 percent phosphoric acid binder (H_3PO_4, water and aluminum hydrate) when cured at 300 degrees F possessed good crushing strength, but the samples were hygroscopic.

In order to eliminate the hygroscopicity, additional binders were prepared in which the percentage of phosphoric acid was reduced and replaced by water in sufficient quantity to produce a thick paste-like composition. The addition of 5 percent of the $Al_2O_3.P_2O_5$ binder containing phosphoric acid, water, aluminum hydrate and alumina to silica sand developed a sand mix of excellent workability. Rammed samples could be cured by air drying as

well as by heat. Baked samples (500 degrees F) were not hygroscopic, had good shelf life and good pyrophysical properties.

Research studies on the phosphates indicated two binders might be applicable to the production of molds or cores which would be suitable for producing steel castings. These binders were basically (1) sodium hexametaphosphate, kaolin and zirconium oxide, and (2) phosphoric acid, water, alumina, and aluminum hydrate.

Casting results for binder No. 1 indicated that this binder in its present state could not be readily adapted to foundry production. Casting results (laboratory) for binder number two were most satisfactory, and it is expected that this binder could be readily adapted to foundry production.

Inasmuch as aluminum phosphate-bonded sand cylinders exhibited satisfactory handling and curing properties on a laboratory basis, an effort was made to reproduce an $Al_2O_3.P_2O_5$ binder without the utilization of phosphoric acid. Monsanto Chemical Company produces a liquid aluminum phosphate sold under the trade name of Alkophos CE.

Laboratory studies with the commercial aluminum phosphate binder were carried on, and it was finally deemed necessary to evaluate it by actual foundry tests. The binder consisted of Alkophos CE and kaolin. The casting results indicated that additional investigations into the $Al_2O_3.P_2O_5.H_2O$ system were needed before this material (Alkophos CE) would be acceptable as a binder for molding sands. Properties deemed desirable were inherently present in this binder, but the surface appearance was rough and pockmarked. This pockmarking was thought to be due to the release of moisture from the bond itself at high temperature.

Ferric Phosphate

A binder based on ferric phosphate is most promising. This material can be dissolved in hot water. A mix containing 5 percent ferric phosphate solution, kaolin and 95 percent silica sand was used to prepare cores and molds. These sands have excellent workability and shelf life, and curing can be accomplished with low pressure compressed air or by air drying. Hot and cold strength tests indicate desirable properties with respect to shake-out, collapsibility and pyroplastic properties. Preliminary casting results are quite promising.

Castable Molds

Investigations have been started to develop a castable sand mold. A slurry of sand, wollastonite and Alkophos CE was prepared. The slurry mixture can be poured into a form, allowed to set and harden in a few minutes. The binder appears to have merit and further investigations are being conducted.

A NEW RESEARCH PROJECT ON DETERMINATION OF THE FACTORS PRODUCING THE CEROXIDE DEFECT

Research Project No. 48

Another research project which was approved the early fall of 1958 was project No. 48. The ceroxide defect is a non-metallic material found in the surface, or slightly under the surface, of steel castings. It appears as a white to green, translucent, slag-like, low-melting material of a combination of silicon dioxide, ferrous oxide, aluminum trioxide, manganous oxide and calcium oxide.

It is observed normally as a shallow depression found mostly on cope surfaces of steel castings. It is easily removed by pressure blasting, leaving a cavity in the casting surface. These cavities are of various sizes from pinpoint to as large as 2 to 3 inches in diameter. They are seldom found in thick-walled large steel castings, but are prevalent in steel castings from a few pounds to several hundred pounds in weight.

This defect results in increased welding and finishing costs. The sub-surface defects affect machinability and tool costs and may affect the mechanical properties of high quality material.

The research is designed to determine the factors contributing to the ceroxide defect and to find a solution to eliminating it or actively controlling it by preventive measures.

Research Procedure

The program of research covers several phases. At the present time, it is believed that the following variables are responsible or contribute to the formation of ceroxides:

1. Eroded ladle refractories.
2. Slag in ladle or pouring basin sucked into the mold cavity through the gates.
3. Gate design and aspiration of deoxidized metal resulting in an oxidation of the alloys of deoxidation, primarily aluminum, calcium, manganese and silicon.
4. Poorly designed sprue and runner gates permitting high velocity steel to erode the gate system; the sand reacting with iron oxide to form a low melting glaze.

5. Agglomeration of finely divided deoxidation products through turbulence in pouring operations. They float out of the steel at the first opportunity of decrease in flow velocity. They are strongly attracted to silica and pick up any loose sand grains present because of erosion.

Studies are going forward at Battelle Memorial Institute. Steel samples showing the ceroxide defect have been requested from member companies, and 33 foundries have responded with 110 examples of the ceroxide defect. Additional samples are welcomed and the member companies are asked to continue sending samples to Mr. F. W. Boulger, Battelle Memorial Institute, Columbus, Ohio.

Microscopic and chemical analyses of a number of the ceroxide defects are being made so as to examine them in all their forms and shapes. Crystallographic analyses and X-ray diffraction studies are also planned.

A casting design is being selected so that the ceroxide defect can be reproduced in the laboratory under controlled conditions. It is planned at the present time to carry on casting studies employing radioactive isotope tracers.

Gating systems employed appear to play a very important part in the frequency of the ceroxide defect. Consideration, therefore, will be given to the following:

a. importance of the pouring basin design
b. tapered vs. parallel-walled sprues
c. tile sprues and runners vs. molding sand
d. multiple ingates vs. single ingate
e. whirl gate vs. none
f. gating ratio, such as 2-1-1 or 2-2-1 vs. 1-1-1 or 1-0.75-1
g. size of sprue, such as 1, 1.5, 2, 2.5 inch diameter
h. effect of poor plastic bonds vs. bonds of high plasticity
i. use ceramic molds to get away from sand

Deoxidation methods have been looked upon as sources of ceroxide, especially methods employing calcium in any form and high residual aluminum contents. Steels are to be prepared with variable quantities of aluminum and calcium under oxidizing and non-oxidizing conditions to determine their effect on ceroxide.

Non-oxidizing conditions have been reported to eliminate ceroxide, such as: (1) pouring in an all oil-sand core mold; (2) shell molds; (3) molds containing neutral or non-oxidizing atmospheres. All of these possibilities are to be studied.

It is the hope of the Technical Research Committee that these studies will be completed by the end of 1959 and that a report covering the findings will follow shortly thereafter.

STUDY OF NON-METALLIC INCLUSIONS IN CASTINGS, USING A RADIOACTIVE TRACER*

by

B. B. Gulyaev and Others

The study of the formation in castings of non-metallic impurities is of sufficient importance for the utilization of a new experimental procedure, as described in what follows, to be of immediate interest to foundrymen. The method employed in the tests here commented upon is the incorporation of a radioactive tracer in the molding mixture

Impurities (non-metallic inclusions) are a type of defect frequently encountered in steel and iron castings. Their formation may often be due to the following causes: erosion of the mold walls by liquid metal; entrainment of ladle slag in the stream of metal; accidental occlusion of dross while pouring, or damage to the mold during assembly. It is important to know the origin of the formation of these impurities in order to overcome the difficulties to which they give rise. Up to the present day, mold erosion has never been experienced while dealing with the straight channels of the gating system. It is known that in the absence of a slag trap in gating systems the amount of inclusions increases, but the cause of this phenomenon is not completely understood. Some authorities say that the slag traps act as collectors of accidentally entrained dross others consider their function to be the softening of the impact caused by the change of direction of the gates. Until now the ways in which the non-metallic inclusions are carried during the mold-filling process have not been studied.

* Translated from the Soviet periodical Liteinoe Proizvodstvo, 1956 (8) Aug. 25-27, and made available by courtesy of the British Steel Castings Research Association.

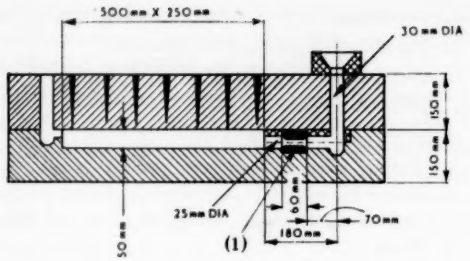

Figure 1—During the investigation of the erosive action of liquid steel or iron on gating walls, in the test molds prepared, the horizontal portions of the gates incorporated core inserts made from a molding mixture containing radioactive material—such an insert can be seen at (1). (1mm = 0.0394 in.)

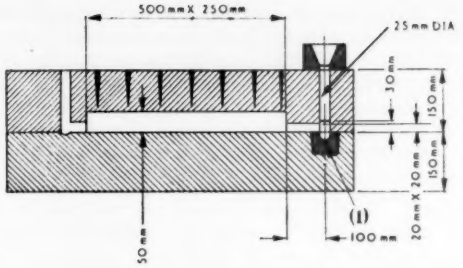

Figure 2—Cross section through a test mold incorporating a radioactive insert, used to study the erosion of the sprue in green-sand molds. The insert can be seen at (1). (1mm = 0.0394 in.)

Testing Procedure

There is now the possibility of using a radioactive tracer in the study of these problems, and the results of investigations using this technique on the formation of non-metallic inclusions, due to mold erosion of the gating system or to the entrainment of dross in the stream of poured metal, will be discussed in what follows. The radioactive tracer was incorporated in the molding mixture. The tungsten isotope W 185 emitting beta and gamma radiation was employed for this purpose.

Molding Mixture

The molding mixture containing the radioactive isotope was prepared in a glass container. To obtain uniform distribution, the radioactive material was introduced in the form of an aqueous suspension, and the composition was mixed throughly for 15 to 20 minutes. The most dangerous parts of the mold from the erosion point of view appear to be the gates, since the linear velocity of metal flow therein is greater than that in the mold cavity itself.

TABLE I—COMPOSITION OF THREE CORE-SAND MIXTURES

Type of Mixture	Composition (weight percent)						
	Quartz Sand	Clay	Water-glass	10 percent Solution of NaOH	Pitch	Drying Oil	Moisture
Green-Sand/Clay	90	10	....	....	....	....	5.5
Water-glass	95	5	6	1	0.5	....	4
Oil-sand	96	4	....	....	....	4	....

Investigation of the erosive action of liquid steel on the gating walls was carried out in clay-bonded sand molds, and the horizontal portions of the gates incorporated core inserts made from a molding mixture containing radioactive material, as can be seen in Figure 1, where (1) illustrates such a core insert. The effect of pouring temperature and binders was also studied.

Preparation of Cores

Cores were prepared from green-sand, oil and water-glass bonded molding mixtures (Table I). Cores made in sand/clay mixtures were kept in a sealed container until the mold was assembled, to avoid their becoming friable; cores made in water-glass and oil-bonded mixtures were dried in an oven at 356 to 392 degrees F for a period of 1.5 to 2 hours.

Castings

Plain carbon steel employed in these investigations was melted in a 1100-pound induction furnace. Liquid-metal temperature was determined by means of a Pt-Pt/Rh thermocouple immersed in the ladle before pouring. Castings were made in the form of plates 20 x 10 x 2 inches. Inclusions carried into the mold cavity as a result of erosion of the core inserts containing the tracer element were located by means of X-ray films applied to the surface of the castings. After cooling in the mold, the castings were separated from the adherent molding mixture and radiographs were obtained. Castings were poured, through cores prepared from sand/clay mixtures, at 2750 degrees F and 2912 degrees F, and radiographs of the casting surfaces were made. At the pouring temperature of 2912 degrees F, the amount of inclusions increased considerably since the superheated metal, having an intimate contact with walls of the mold, eroded these intensely by a process of solid skin formation.

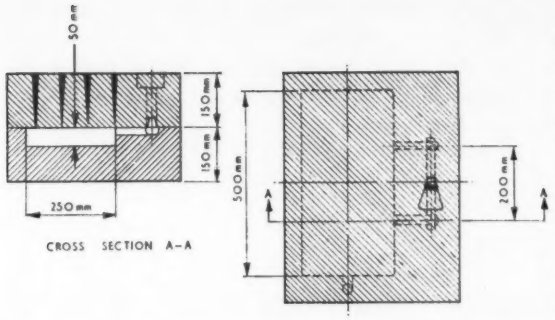

Figure 3—Vertical cross section (left) and underside of one of the three types of clay-bonded molds used in the tests with tungsten isotope W 185. See Table II. (1mm = 0.0394 in.)

Results and Conclusions

Radiographs of surfaces of castings which were poured through core inserts made of various molding mixtures were made. The greatest amount of inclusions occurred when cores prepared from green-sand/clay mixture were used; the amount of inclusions decreased when cores prepared from a mixture containing water-glass were employed; a further drop in the amount of inclusions occurred with oil-bonded cores. Evidently, the varying erosion of molding mixtures is related to the surface strength of the cores in the period of contact with the liquid metal. The force required to pull sand grains from the surface of the mold increases with the strength of the molding mixture.

To study the erosion of the sprue in green-sand molds, an insert incorporating a radioactive material was used so as to form the base of the sprue as is shown in Figure 2, where (1) denotes the insert. Inserts forming the base of the sprue were of varying shapes: (a) without a sprue base, (b) with a semi-spheroidal sprue base having a radius equal to that of the sprue, and (c) with a deep sprue base.

These core inserts were prepared from sand/clay mixtures and rammed by three blows of a standard laboratory rammer. To assess the effect of ramming density, tests were also made with core inserts compacted with six blows of the rammer. The results of tests in which the different sprue base inserts were used were brought together in the form of radiographs. Provision of a special sprue base serves the following purposes: to lessen the impact of the stream liquid metal; to reduce its erosive action on the sprue base and, consequently, to reduce the amount of inclusions in the surface regions of the plate. The best results are obtained with gating systems employing the deep semi-spheroidal sprue bases. Higher ramming density also decreases considerably the erosion of mold walls. Vertical sections of the castings show that inclusions concentrate in the vicinity of the top surface. Near the bottom surfaces a small number of fine inclusions, washed away from the surfaces of the gating channels, are present. Obviously these inclusions have not succeeded in rising to the top and remain occluded in the crust of the solidifying bottom surface.

Table II—Size Ratios of the Experimental Gating Systems Used

Ratio			Cross-Sectional Areas (sq. in.)		
Sprue	Runner	Ingate	Sprue	Runner	Ingate
1.0	1.2	1.4	0.89	1.07	1.24
1.4	1.2	1.0	1.74	1.49	1.24
1.0	1.0	1.0	1.24	1.24	1.24

The investigation made demonstrated that at sufficiently high metal temperature and low strength of the molding mixture, erosion of the surface layers of the gating system occurs easily, and that the entrained particles are carried by the metal stream into the casting. Maximum erosion takes place at the bends in the gating system, and to a lesser extent along the horizontal parts of the system.

Gating System

In order to determine the effect of the gating system design on the entrainment of slag inclusions, and the nature of the distribution of these inclusions in castings, tests were carried out in which molding mixture containing radioactive tracer was poured on the surface of metal in the pouring basin. In view of the fact that the probability of entraining slag inclusions into gating systems is greater in the case of ladle-poured iron, than in pouring steel, the former was used for making test castings. In these tests, three types of clay-bonded molds were used; Figrue 3 illustrates one of these types. Dimensions of the cross sections and the ratios of the components of the gating systems are listed in Table II.

Iron was poured into the molds at a temperature of 2372 degrees F within 20 to 30 seconds. For a period of 5 seconds after the beginning of pouring, non-metallic particles were introduced in the form of clay molding mixture containing the radioactive isotope of tungsten. Radiographs of the distribution of the slag particles in the top surface layers of the iron plates show that these inclusions are retained to approximately the same extent by all three types of gating systems, and in each case a change of the ratios of the cross sections of the gating system components did not affect the retention of slag. Provisional calculations show that sand grains having a diameter of 0.079 to 0.108 inch cannot succeed in rising to the top surface in the time taken by the stream of metal to get to the mold.

A radiograph of a typical section of a gating system shows that the slag inclusions in the channels of the gating system are concentrated chiefly at the bends where the stream of metal changes direction, and the greatest concentration occurs at the joint of slag trap and feeding head. The metal stream loses its velocity at the bend and facilitates thereby the rise of slag particles. Fine particles, having an insufficient velocity of rising, are carried by the metal stream and are forced toward the regions of the bottom surface of the casting; whereas the larger ones succeed in getting to the surface and distribute themselves in the top surface layers of the castings, mainly near the base of the feeding head.

SOME EXPERIMENTS ON 13 PERCENT CHROMIUM CAST STEEL

by

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TABLE I

	Industrial Uses	Chemical Composition (Percent)					
		C	Si	Mn	P	S	Cr
I	Materials in which corrosion resistance and machinability were required	0.13 max	0.8-1.2	0.6 max	0.04 max	0.04 max	12-15
II	Structural quality in which ductility was required	0.15-0.20	0.3-0.5	0.5 max	0.04 max	0.04 max	12-13
III	Materials in which high strength, cavitation and wear resistance were required	0.3-0.4	1.0 max	0.5 max	0.04 max	0.04 max	12-13

The authors studied the fluidity, machinability, corrosion resistance, weldability and mechanical properties of 13 percent chromium cast steel. The results of the study were as follows:

(1) It was recommended that materials of the compositions shown in Table I be used in accordance with their proper applications. An addition of 0.5 to 1.0 percent nickel should be made to the alloy when high hardness is required and 0.1 to 0.25 percent aluminum should be added if increased ductility is desired.

(2) Machinability was found to be best when the material was in the annealed condition.

(3) The most favorable mechanical properties were obtained by quenching from 1830 degrees F and tempering at 1290 to 1380 degrees F.

(4) Annealing brittleness may result from precipitation of carbides at the grain boundaries. This condition is minimized by a normalizing treatment.

(5) Welding of this alloy is best accomplished using reverse polarity and 13 percent chrome or 10 percent nickel - 20 percent chrome electrodes.

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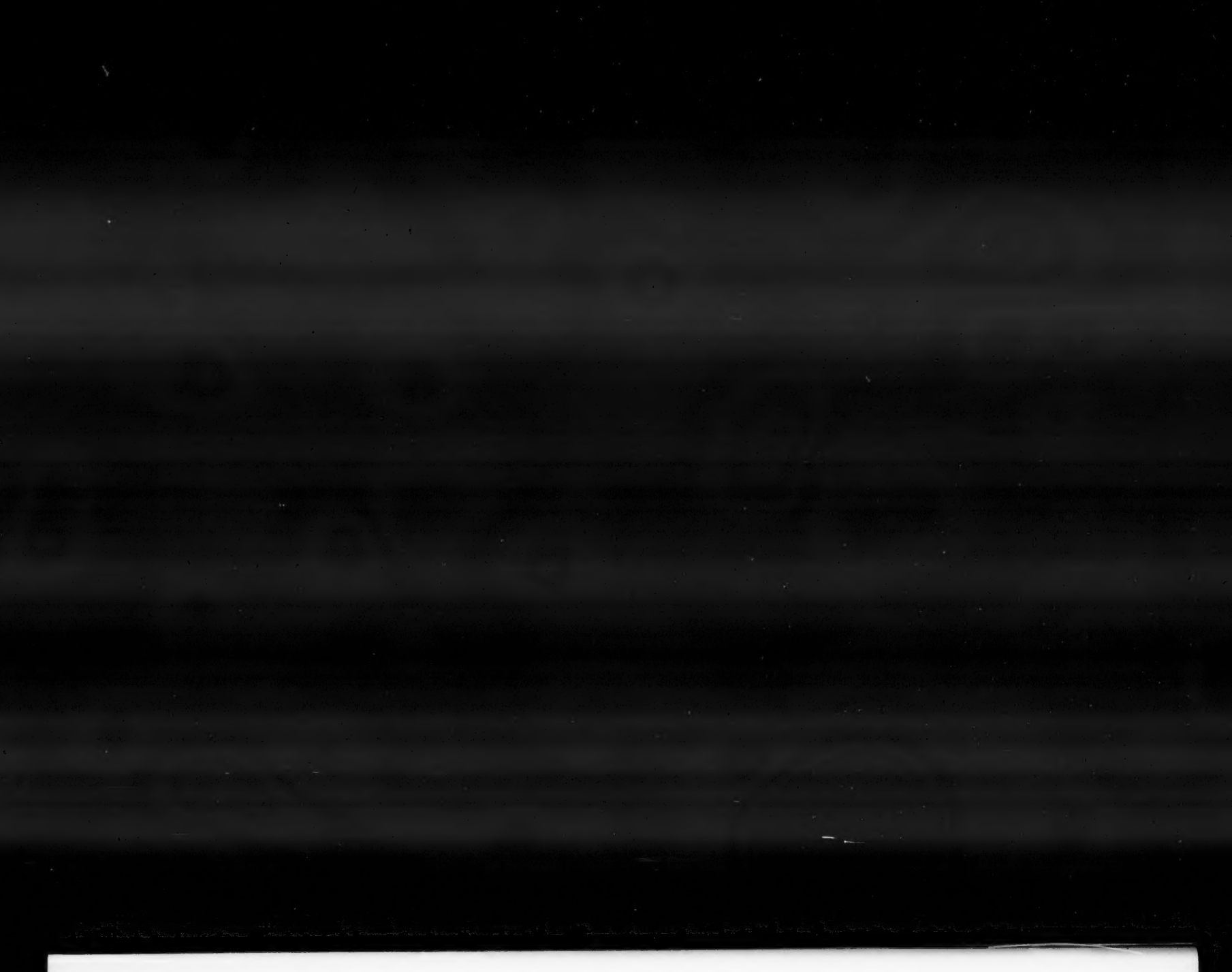
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